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SIR:

CERTIFIED TRANSLATION

I, Naomi YOKOYAMA, am an official translator of the Japanese language into the English language and I hereby certify that the attached comprises an accurate translation into English of Japanese Application No. 2000-227888, filed on July 27, 2000.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United states Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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[Title of the Invention] LIQUID CRYSTAL DISPLAY DEVICE

[Claims]

[Claim 1] A liquid crystal display device of a vertical-alignment mode, comprising:

a driving substrate having a pixel electrode;

a counter substrate opposing said driving substrate and having a counter electrode; and

a liquid crystal sandwiched between said substrates,

wherein molecules of said liquid crystal are aligned nearly perpendicularly to said substrates when no electric field is produced, and are aligned nearly horizontally by the application of a predetermined voltage,

wherein said counter substrate has an alignment center portion for orienting said molecules of said liquid crystal in all directions centered on a certain point when the voltage is applied, and

wherein the area of said alignment center portion of said counter substrate is set to be less than or equal to 5% of the area of one pixel.

[Claim 2] A liquid crystal display device according to claim 1, wherein said alignment center portion is a protuberance or an alignment disturbing surface.

[Claim 3] A liquid crystal display device according to claim 2, wherein the base area of said protuberance is

within the range of 50 μm² to 225 μm².

[Claim 4] A liquid crystal display device according to claim 2, wherein the area of said alignment disturbing surface is less than or equal to 225 μm².

[Claim 5] A liquid crystal display device according to any one of claims 1 to 4, wherein said pixel electrode of said driving substrate or said counter substrate is provided with a slit, a cut, or a hole for making multi-domain alignment of said liquid crystal nearly vertically or horizontally symmetric.

[Claim 6] A liquid crystal display device according to any one of claims 1 to 5, wherein a chiral material is added to said liquid crystal.

[Claim 7] A liquid crystal display device according to claim 6, wherein the chiral pitch L and the cell gap d of said liquid crystal have a relation $2.5 < L/d < 5.5$.

[Claim 8] A liquid crystal display device according to any one of claims 1 to 7, wherein said liquid crystal display device is of an active matrix type.

[Claim 9] A liquid crystal display device according to claim 8, wherein the pixel pitch is less than or equal to 70 μm.

[Claim 10] A liquid crystal display device according to any one of claims 1 to 9, wherein a retardation film for compensating the viewing angle is provided between said

driving substrate or said counter substrate, and a polarizer on the outside of said driving substrate or said counter substrate, and the following conditions are satisfied:

[Equation 1]

$$0.7 < \frac{\Delta n d_{LC}}{(\frac{Nx + Ny}{2} - Nz) \cdot d_{film}} < 1.3$$

$(Nx\text{-}Ny) \cdot d_{film} < 100$ nm

where Nx and Ny represent the refractive indices of said retardation film in the in-plane directions, Nz represents the refractive index in the thickness direction, d_{film} represents the thickness, Δn represents the refractive index anisotropy of said liquid crystal, and d_{LC} represents the cell gap.

[Claim 11] A production method for a liquid crystal display device of a vertical-alignment mode in which a driving substrate having a pixel electrode and a counter substrate having a counter electrode are opposed to each other, a liquid crystal is sandwiched between said substrates, and molecules of said liquid crystal are aligned nearly perpendicularly to said substrates when no electric field is produced, and are aligned nearly horizontally by the application of a predetermined voltage,

wherein said counter substrate has an alignment center portion for orientating said molecules of said liquid crystal in all directions centered on a certain point when

the voltage is applied, and

wherein the area of said alignment center portion of said counter substrate is set to be less than or equal to 5% of the area of one pixel.

[Claim 12] A production method for a liquid crystal display device according to claim 11, wherein a protuberance is formed as said alignment center portion by applying a photosensitive resin onto said counter substrate, and patterning said photosensitive resin.

[Claim 13] A production method for a liquid crystal display device according to claim 12, wherein the base area of said protuberance is within the range of 50 μm^2 to 225 μm^2.

[Claim 14] A production method for a liquid crystal display device according to claim 11, wherein an alignment disturbing surface is formed as said alignment center portion by applying different types of alignment films, or by applying UV light, polarized light, or an ion beam.

[Claim 15] A production method for a liquid crystal display device according to any one of claims 11 to 14, wherein said driving substrate or said counter substrate is provided with a slit, a cut, or a hole for making multi-domain alignment of said liquid crystal nearly vertically or horizontally symmetric.

[Claim 16] A production method for a liquid crystal display device according to any one of claims 11 to 15,

wherein a chiral material is added to said liquid crystal.

[Claim 17] A production method for a liquid crystal display device according to claim 16, wherein the chiral pitch L and the cell gap d of said liquid crystal have a relation $2.5 < L/d < 5.5$.

[Claim 18] A production method for a liquid crystal display device according to any one of claims 11 to 17, wherein a TFT substrate is used as said driving substrate.

[Claim 19] A production method for a liquid crystal display device according to claim 18, wherein the pixel pitch is less than or equal to 70 μm.

[Claim 20] A production method for a liquid crystal display device according to any one of claims 11 to 19, wherein a retardation film for compensating the viewing angle is provided between said driving substrate or said counter substrate, and a polarizer on the outside of said driving substrate or said counter substrate, and the following conditions are satisfied:

[Equation 2]

$$0.7 < \frac{\Delta nd_{LC}}{(\frac{Nx+Ny}{2} - Nz) \cdot d_{film}} < 1.3$$

$$(Nx-Ny) \cdot d_{film} < 100 \text{ nm}$$

where Nx and Ny represent the refractive indices of said retardation film in the in-plane directions, Nz represents the refractive index in the thickness direction, d_{film}

represents the thickness, Δn represents the refractive index anisotropy of said liquid crystal, and d_{LC} represents the cell gap.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to a multi-domain vertical-alignment liquid crystal display device which achieves a wide viewing angle without decreasing the effective aperture ratio.

[0002]

[Description of the Related Art]

In presently available liquid crystal display devices, a TN (Twisted Nematic) mode is generally used as a liquid crystal display mode. In the TN mode, however, the viewing angle is narrow, and tone reversal occurs when the screen is viewed from an oblique direction, which remarkably reduces the display quality. Moreover, the response speed is low in a halftone region and the outlines of displayed video pictures are not clear. Such problems of the TN mode cannot be completely overcome even by phase compensation.

[0003]

As the alternatives to the TN mode, various liquid crystal display modes, such as an IPS (In-Plane Switching) mode, an OCB (Optical Compensated Birefringence) mode, and a

multi-domain vertical-alignment (multi vertical alignment: MVA) mode, have recently been developed. Above all, the multi-domain vertical-alignment mode has received attention as a technique of increasing the viewing angle.

[0004]

In the multi-domain vertical-alignment mode, for example, a method using electrode slits (SID 97 DIGEST p. 461), and a method using protuberances on the surface of a substrate (Japanese Patent No. 2947350) have been proposed to carry out multi-domain alignment of the liquid crystal. Furthermore, in order to improve the transmittance of the liquid crystal display device of the multi-domain vertical-alignment mode and to overcome the problem of color shifting among the tones, methods for adding a chiral material and making a twisted orientation in a state in which a voltage is applied have been proposed (for example, Japanese Unexamined Patent Application Publication No. 11-352490, Japanese Unexamined Patent Application (by PCT route) Publication No. 10-506479, SID 91 DIGEST pp.762-765, 1991, and SID 92 DIGEST pp.33-35, 1992).

[0005]

[Problems to be Solved by the Invention]

In the liquid crystal display devices of the multi-domain vertical-alignment mode, however, the viewing angle cannot be increased satisfactorily, and the transmittance is

sacrificed to increase the viewing angle. In particular, the protuberances and electrode slits formed on the surfaces of the substrates for the purpose of controlling the alignment do not serve as effective apertures, thus lowering the transmittance.

[0006]

Accordingly, it is an object of the present invention to achieve a wide viewing angle without lowering the effective aperture ratio in a liquid crystal display device of a multi-domain vertical-alignment mode.

[0007]

[Means for Solving the Problems]

The present inventors found that it is effective, in achieving a wide viewing angle in a liquid crystal display device of a vertical-alignment mode, to form an alignment center portion, such as a protuberance or an alignment disturbing surface, on a counter substrate opposing pixel electrodes so that molecules of the liquid crystal are oriented in all directions centered on the alignment center portion when a voltage is applied. The present inventors also found that it is necessary, in order to prevent the effective aperture ratio from decreasing, to set the ratio of the area of the alignment center portion of the counter substrate (that is, the base area of a protuberance serving as the alignment center portion, or the surface area of an

alignment disturbing surface serving as the alignment center portion) to the area of one pixel so as to be less than or equal to a predetermined ratio.

[0008]

That is, the present invention provides a liquid crystal display device of a vertical-alignment mode which includes a driving substrate having a pixel electrode, a counter substrate opposing the driving substrate and having a counter electrode, and a liquid crystal sandwiched between the substrates, and in which molecules of the liquid crystal are aligned nearly perpendicularly to the substrates when no electric field is produced, and are aligned nearly horizontally by the application of a predetermined voltage. The counter substrate has an alignment center portion for orienting the molecules of the liquid crystal in all directions centered on a certain point when the voltage is applied, and the area of the alignment center portion of the counter substrate is set to be less than or equal to 5% of the area of one pixel.

[0009]

Furthermore, the present invention provides a production method for a liquid crystal display device of a vertical-alignment mode in which a driving substrate having a pixel electrode and a counter substrate having a counter electrode are opposed to each other, a liquid crystal is

sandwiched between the substrates, and molecules of the liquid crystal are aligned nearly perpendicularly to the substrates when no electric field is produced, and are aligned nearly horizontally by the application of a predetermined voltage. The counter substrate has an alignment center portion for orienting the molecules of the liquid crystal in all directions centered on a certain point when the voltage is applied, and the area of the alignment center portion of the counter substrate is set to be less than or equal to 5% of the area of one pixel.

[0010]

[Description of the Embodiments]

The present invention will be described in detail below in conjunction with an active matrix liquid crystal display device with reference to the drawings, whereas the present invention is also applicable to a passive matrix liquid crystal display device having pixel electrodes arranged in stripes. In the drawings, the same reference numerals denote the same or equivalent components.

[0011]

Fig. 1(a) and 1(b) are a schematic plan view and a sectional view, respectively, of an active matrix liquid crystal display device 100 according to an embodiment of the present invention.

[0012]

The liquid crystal display device 100 has, as a driving substrate 2, a TFT substrate with pixel electrodes 1 made of ITO. A counter substrate 4 having counter electrodes 3 made of ITO, and the driving substrate 2 oppose each other, and liquid crystal 5 is sandwiched between the substrates 2 and 4. The upper surfaces of the pixel electrodes 1 and the counter electrodes 3 are coated with a vertical alignment film. Molecules of the liquid crystal 5 are aligned nearly perpendicularly to the driving substrate 2 or the counter substrate 4 when no electric field is applied, are obliquely tilted by the application of a voltage, and are aligned nearly horizontally by applying a voltage higher than or equal to a predetermined voltage. Polarizers (not shown) are provided on the outer sides of the driving substrate 2 and the counter substrate 4, and are arranged in a crossed-Nicol form, as shown by the arrows on the upper right side of Fig. 1.

[0013]

A protuberance 6 is provided at the center of the counter substrate 4 so as to function as an alignment center portion that orients the molecules of the liquid crystal 5 in all directions. In order to prevent the aperture ratio from decreasing, the size of the protuberance 6 is determined so that the area of the protuberance 6 in the counter substrate 4, that is, the base area of the

protuberance 6, is lower than or equal to 5% of the area of one pixel. In particular, in a case in which the protuberance 6 is formed by proximity exposure, it is preferable that the base area be set within the range of 50 μm^2 to 225 μm^2. In a case in which the protuberance 6 is formed by step-and-repeat exposure, the base area may be less than or equal to 25 μm^2.

[0014]

The height of the protuberance 6 is not particularly limited. In general, in order to maintain the gap between the substrates in the liquid crystal display device, spherical spacers are dispersed on the substrates, or resin struts are provided on the substrates. By setting the height of the protuberance 6 to be equal to the gap between the substrates, the protuberance 6 can also function as a spacer, and this can eliminate the process of dispersing the spacers or forming the strut-shaped spacers. It is also possible to avoid a gap defect due to variations in dispersion density of the spacers.

[0015]

The protuberance 6 controls the alignment so that the molecules of the liquid crystal 5 are tilted when an electric field is not applied, and so that an oblique electric field is produced by distortion of electric lines of force and the molecules are oriented in all directions

centered on the protuberance 6 when a voltage is applied, as will be described later. For this reason, in order to effectively control the orientation when a voltage is applied, it is preferable that the protuberance 6 be made of a material having a dielectric constant lower than that of the liquid crystal 5, and more preferably, be made of a material having a dielectric constant less than or equal to 5. Preferable materials of the protuberance 6 are, for example, acrylic, novolac, and polystyrene photosensitive resins.

[0016]

While the protuberance 6 shown in Fig. 1 is shaped like a quadrangular prism which is rounded at the top, it may be shaped like any type of cone, an inverted hemisphere, a column, or the like. As will be described later, in order to produce an oblique electric field by the protuberance 6 so as to tilt the liquid crystal molecules, it is preferable that the protuberance 6 be triangular or semicircular in cross section taken in a direction perpendicular to the driving substrate 2 or the counter substrate 4. Whichever the cross section is triangular or semicircular, similar advantages can be obtained. From the viewpoint of ease of forming, it is more preferable that the protuberance 6 be semicircular. It is undesirable to make the protuberance 6 linear because this lowers the contrast and transmittance.

[0017]

The semicircular protuberance 6 is formed by, for example, applying a positive photosensitive resin on the counter substrate 4, subjecting the resin to exposure, development, and patterning, prebaking the resin at 100°C to 200°C, at which the resin is not immediately set, and then finally baking the resin. A desired shape can be obtained by adjusting the period and temperature of prebaking. Alternatively, as shown in Fig. 2, a pattern 6′ is formed by using a mask 11a having a halftone portion 12 serving as a patterning mask (Fig. 2(a)), and is baked to form a semicircular protuberance 6 (Fig. 2(b)). Alternatively, as shown in Fig. 3, a pattern 6″ is formed by using a mask 11b having narrow slits 13 serving as a patterning mask, and is further baked to form a semicircular protuberance 6 (Fig. 3(b)). The use of such masks 11a and 11b allows the shape control to be exerted more finely.

[0018]

Operation of the liquid crystal display device 100 shown in Fig. 1 will now be described. In the liquid crystal display device 100, the molecules of the liquid crystal 5 are aligned nearly perpendicularly to the driving substrate 2 or the counter substrate 4 when no electric field is applied. When a voltage is applied thereto, spaces w between the adjoining pixel electrodes 1 of the driving

substrate 2 function as electrode slits, and a transverse electric field is thereby formed, as shown by dotted equipotential lines in Fig. 1(b). The transverse electric field becomes an oblique electric field adjacent to the protuberance 6. For this reason, the liquid crystal molecules radially tilt centered on the protuberance 6 when a voltage is applied, and are oriented in all directions, as shown by arrows in Fig. 1(a). Accordingly, the liquid crystal display device 100 has improved viewing angle characteristics.

[0019]

In contrast, in a case in which the protuberance 6 serving as the alignment center portion is not provided on the counter substrate 4, the liquid crystal molecules tend to be tilted by the transverse electric field formed by the application of the voltage. In this case, however, since the alignment center portion is not provided, the liquid crystal molecules are oriented centered on a point called a disclination. Since the disclination point is unstable and is displaced depending on the conditions, such as the unevenness of the substrate and the potential of the adjoining pixel, the orientation cannot be controlled sufficiently. This reduces the display quality of the liquid crystal display device, and the display is nonuniform.

[0020]

In the present invention, the fact that the liquid crystal molecules are oriented in all directions centered on a certain point does not always mean that the molecules are uniformly distributed in all directions, and the molecules may be oriented only in some directions. For example, in the liquid crystal display device shown in Fig. 1(a), the percentage of the molecules of the liquid crystal 5, which point in four directions, that is, the 0, 3, 6, and 9 o'clock directions, is high. However, clear boundaries between the orientation directions exist only adjacent to the protuberance 6 serving as the alignment center portion, and the liquid crystal molecules are continuously oriented around the protuberance 6. In the present invention, such an orientation state is also included in the state in which the molecules of the liquid crystal 5 are oriented in all directions centered on the protuberance 6.

[0021]

In the liquid crystal display device 100, light does not pass through the spaces w between the adjoining pixel electrodes 1 during a white display state in which a voltage is applied. In general, the spaces w include data lines, gate lines, and the like, and therefore, are not opened. The base area of the protuberance 6 is set to be less than or equal to 5% of the area of one pixel. Accordingly, there is little loss of aperture ratio in the liquid crystal

display device 100.

[0022]

The liquid crystal display device of the present invention includes various embodiments other than the embodiment shown in Fig. 1. For example, instead of the protuberance 6, an alignment disturbing surface for disturbing the alignment may be provided on the counter substrate 4 so as to serve as an alignment center portion that orients the liquid crystal molecules in all directions when a voltage is applied. The alignment disturbing surface is formed by applying different types of alignment films, for example, by applying a horizontal alignment film only onto the alignment center portion of the counter substrate 4 without applying a vertical alignment film thereon. By exposing the alignment center portion of the counter substrate 4 with UV light, the alignment thereat may be disturbed. Alternatively, a predetermined orientation direction different from that of the peripheral portion may be obtained by applying polarized light to the alignment center portion.

[0023]

Fine projections and depressions may be formed on an underlayer of the alignment center portion. More specifically, for example, only the surface of the alignment center portion is roughened with the application of an ion

beam by a photoresist process before a vertical alignment film is formed, or an ITO transparent electrode of a different quality is formed only in the alignment center portion by a photoresist process.

[0024]

In a case in which the alignment disturbing surface is provided as the alignment center portion on the counter substrate 4, the area of the alignment disturbing surface on the counter substrate 4 is also set to be less than or equal to 5% of the area of one pixel, more preferably, to be 0.1% to 1%, in order to prevent the aperture ratio from decreasing.

[0025]

In general, the pixels of a color liquid crystal display device are divided into three colors, R, G, and B, and each of the R, G, and B pixels is not square, but is rectangular in most cases. In such cases, in order to obtain a more symmetric viewing angle, or to also sufficiently control the alignment in the longitudinal direction of the pixel, the pixel electrode 1 or the counter electrode 3 may be provided with a slit, a cut, or a hole so that the multi-domain alignment of the liquid crystal becomes nearly vertically or horizontally symmetric, and ideally, circular. For example, as shown in Figs. 4(a) to 4(i), slits 7 and cuts 8 are formed in one pixel of the

pixel electrode 1 so as to make the multi-domain alignment of the liquid crystal nearly vertically or horizontally symmetric, and protuberances 6 are formed on the counter electrode 3. In these figures, the slits 7 and the cuts 8 provided in the pixel electrode 1 may be provided in the counter electrode 3. Alternatively, in these figures, the protuberances 6 may be replaced with holes. The alignment center portion for the liquid crystal alignment may be formed in the pixel electrode 1. For example, as shown in Fig. 4(j), a slit 7 and holes 9 may be formed in the pixel electrode 1.

[0026]

The slits 7, the cuts 8, or the holes 9 are formed by, for example, ITO patterning ITO in a photoresist process. In particular, in a case in which a slit 7 is formed in the pixel electrode 1, it can be formed without increasing the number of processes because the pixel electrode 1 itself is originally formed by ITO patterning.

[0027]

In the present invention, a chiral material may be added to the liquid crystal 5. The addition of the chiral material can stabilize the alignment when a voltage is applied.

[0028]

In the liquid crystal display device sandwiched between

the polarizers arranged in a crossed-Nicol form, when the liquid crystal molecules are not oriented in a twisted manner, the transmittance greatly depends on the angle formed between the aligning direction of the liquid crystal molecules and the absorption axis or the polarization axis of the polarizers. When the aligning direction of the liquid crystal molecules coincides with the absorption axis or the polarization axis of the polarizers, little light is transmitted, thus causing a black display state. For this reason, in the liquid crystal display device 100 shown in Fig. 1, the liquid crystal molecules oriented in the same direction as that of the absorption axis or the polarization axis of the polarizers, of the molecules tilting horizontally in a white display state in which a voltage is applied, do not transmit light. This lowers the transmittance. The addition of a chiral material is also effective in solving such a problem of decreased transmittance. Since the liquid crystal molecules themselves are oriented in a twisted manner by adding the chiral material, a black display is not produced in a crossed-Nicol arrangement regardless of the alignment direction, and the dependency of the transmittance on the angle between the liquid crystal alignment direction and the absorption axis or the polarization axis of the polarizers can be reduced. Furthermore, by adjusting the chiral pitch

so that the liquid crystal molecules are oriented in a twisted manner when a voltage is applied, a high transmittance can be obtained.

[0029]

In a case in which the liquid crystal molecules are oriented in a twisted manner, the transmittance is highest when the apparent twist angle when a voltage is applied (white display) is approximately 90°. On the other hand, a voltage of 3.5 V to 6 V is usually applied when a white display is produced, and the threshold value of the liquid crystal is approximately 2 V. From the above, in order to maximize the transmittance, it is preferable that the liquid crystal chiral pitch L and the cell gap d have a relationship $2.5 < L/d < 5.5$. In order to satisfy this condition, it is preferable that the product Δnd of the refractive index anisotropy Δn with respect to a wavelength of 589 nm and the cell gap d be within the range of 400 nm to 700 nm.

[0030]

Since the response speed of the liquid crystal display device greatly depends on the cell gap d, it is preferable that Δn be as high as possible in the above condition. More specifically, in order to achieve excellent motion picture display, it is preferable that the refractive index anisotropy Δn of the liquid crystal with respect to 589 nm

be more than or equal to 0.115.

[0031]

A color separation filter is provided for each pixel in the color liquid crystal display device. The transmittance of the liquid crystal display device greatly depends on $\Delta n_{eff} \times d/\lambda$, where Δn_{eff} represents the apparent refractive index anisotropy of the liquid crystal layer, d represents the cell gap, and λ represents the wavelength. This shows that the transmittance greatly depends on the wavelength of light. Even if $\Delta n_{eff} \times d$ is set to be most suitable for a certain wavelength, it is not suitable for another wavelength, and therefore, changes in color balance appear on the display. Such color balance changes appear, in particular, when the display is viewed from an oblique direction. While the dependency of the transmittance on λ is relatively low in a TN mode, it is high in a vertical-alignment mode adopted in the present invention. This is because the liquid crystal molecules are oriented in all directions when a voltage is applied, and a birefringent mode is mixed even when the liquid crystal molecules are oriented in a twisted manner. In order to improve such a characteristic, it is preferable to set the cell gap d so as to be most suitable for the principal wavelength λ of each pixel color.

[0032]

Various methods for changing the cell gap d in accordance with the principal wavelength λ of each pixel color have been proposed. Among them, a method for changing the thicknesses of the color filters depending on the colors is most preferable because this does not increase the number of processes.

[0033]

Since the liquid crystal display device of the present invention adopts a vertical alignment mode, a wider viewing angle can be obtained by compensation using a biaxial or uniaxial retardation film.

[0034]

In order to obtain a wide viewing angle in actual use, it is preferable that the retardation film satisfy the following conditions:

[Equation 3]

$$0.7 < \frac{\Delta n d_{LC}}{\left(\frac{Nx + Ny}{2} - Nz\right) \cdot d_{film}} < 1.3$$

$(Nx-Ny) \cdot d_{film} < 100$ nm

where Nx and Ny represent the refractive indices of the retardation film in the in-plane directions, Nz represents the refractive index in the thickness direction, d_{film} represents the thickness, Δn represents the refractive index anisotropy of the liquid crystal, and d_{LC} represents the cell gap.

[0035]

Although not particularly limited, it is preferable that the liquid crystal display device of the present invention be driven by an active matrix addressing method, as shown in Fig. 1. In the active matrix addressing, the spaces between the adjoining pixel electrodes 1 can be positively utilized as electrode slits for controlling the alignment, and this eliminates the necessity of forming new electrode slits on the driving substrate 2 in order to form a transverse electric field. In a case in which an electrode slit is formed in the pixel electrode 1, as necessary, the pattern of the slit can be more freely formed than in the passive matrix addressing using the electrodes arranged in stripes. While the counter electrodes 3 on the counter substrate 4 are patterned in stripes in the passive matrix addressing, the counter electrodes 3 on the counter substrate 4 in the active matrix addressing are usually not patterned. Consequently, an oblique electric field or the like for disturbing a predetermined alignment control will now be produced.

[0036]

In an active matrix liquid crystal display device, it is preferable that the pitch of one pixel be set so that an alignment control force satisfactorily acts. From this viewpoint, it is preferable that the pitch of one pixel be

less than or equal to 70 μm.

[0037]

Fig. 5 is a sectional view showing an example in which the liquid crystal display device of the present invention is applied to a liquid crystal panel of an active matrix type. The liquid crystal panel has a structure in which a TFT substrate 2′ is used as a driving substrate, a color filter substrate 4′ is used as a counter substrate, and liquid crystal 5 is sandwiched between the substrates.

[0038]

The color filter substrate 4′ includes red (R), green (G), and blue (B) color filters 15 arranged in stripes on a glass substrate 14, and an ITO transparent electrode serving as a counter electrode 3 provided thereon. Protuberances 6 are provided on the surface of the counter electrode 3 on the side of the liquid crystal corresponding to pixel electrodes 1 in the TFT substrate 2′, and a vertical alignment film 16 is provided thereon.

[0039]

In contrast, the TFT substrate 2′ has a structure in which TFT elements (not shown) and wires, such as signal lines 18, are provided on a glass substrate 17, and a planarizing film 19, the pixel electrodes 1, and a vertical alignment film 16 are sequentially disposed thereon.

[0040]

Retardation films 20a and 20b, and polarizers 21a and 21b arranged in a crossed-Nicol form are provided on the outer sides, that is, a light-incident side (the side of the TFT substrate 2') and a light-emergent side (the side of the color filter substrate 4') of the liquid crystal panel, respectively.

[0041]

[Examples]

The present invention will be specifically described with reference to examples.

[0042]

First Example

The liquid crystal panel shown in Fig. 5 was produced in the following manner.

[0043]

Rectangular patterns each having a bottom surface with four sides of 7 μm were formed by applying a positive photosensitive resin on a color filter substrate 4', in which red (R), green (G), and blue (B) color filters 15 having a thickness of 1.2 μm were arranged in stripes on a glass substrate 14, and an ITO transparent electrode of 100 nm in thickness was formed thereon, and subjecting the photosensitive resin to exposure and development. In order to obtain a more desirable shape, the photosensitive resin was baked at 120°C to 180°C for five minutes, and was finally

backed at a temperature higher than or equal to 200°C. Protuberances 6 of semicircular cross section having a height of 1.5 μm were thereby obtained. The dielectric constant of the protuberances 6 was 3. A polyimide vertical alignment film was printed on the surface where the protuberances 6 were formed, and was baked at 180°C for one hour. A vertical alignment film 16 thus obtained had a thickness of 50 nm to 100 nm. The vertical alignment film 16 was not subjected to rubbing.

[0044]

On the other hand, a TFT substrate 2' was prepared in which TFT elements and wires, such as signal lines 18, were provided on a glass substrate 17, a planarizing film 19 having a thickness of 3 μm was provided thereon, and ITO electrodes having a thickness of 100 μm were formed thereon as pixel electrodes 1. Each pixel electrode 1 had a width of 40 μm and a length of 120 μm, and spaces w_1, w_2, w_3, and w_4 (see Fig. 1) between the pixel electrode 1 and the adjoining pixel electrodes were set at 7 μm. A vertical alignment film 16 was formed on the pixel electrodes 1 in a manner similar to that in the color filter substrate 4'. Next, a common transfer material was applied, and acrylic spacers (having a particle diameter of 3.5 μm) were dispersed.

[0045]

Sealing agent was applied onto the above-described color filter substrate 4', the color filter substrate 4' and the TFT substrate 2' were placed one on the other and were baked at 13.3 Pa (0.1 torr) and 120°C for two hours. Subsequently, liquid crystal 5 was injected into the panel in a vacuum. The liquid crystal 5 had $\Delta\varepsilon$ of -4, Δn of 0.12, and a chiral pitch of 13 μm.

[0046]

Retardation films 20a and 20b, and polarizers 21a and 21b arranged in a crossed-Nicol form were sequentially bonded to the outer sides of the TFT substrate 2' and the color filter substrate 4', respectively. In this case, the retardation films 20a and 20b had a phase difference only in the thickness direction (Z-axis direction), and satisfied the following condition:

$(N_X - N_Z)d = 300$ nm

(N_X represent the refractive index in the in-plane direction, N_Z represents the refractive index in the thickness direction, and d represents the thickness of the retardation film).

[0047]

The polarizers 21a and 21b were formed of triacetate films which had a phase difference in the z-axis direction and provided advantages similar to those of the retardation films 20a and 20b.

[0048]

The liquid crystal panel thus obtained was inversely driven for one hour. As a result, the liquid crystal panel showed excellent viewing angle characteristics in which serious contrast decrease and tone reversal did not appear in all directions.

[0049]

Second Example

A liquid crystal panel was produced in which the pixel electrodes 1 on the TFT substrate 2′ and the protuberances 6 on the color filter substrate 4′ in the first example were arranged and patterned, as shown in Fig. 4(a). In this case, the width L_1 of slits 7 in the color filter substrate 4′ was set at 7 μm.

[0050]

As the result of evaluating the driving of the obtained liquid crystal panel in a manner similar to that in the first example, excellent viewing angle characteristics were achieved in which serious contrast decrease and tone reversal did not appear in all directions. Furthermore, the viewing angle characteristics were more highly symmetric with respect to the azimuth direction than in the first example. Regarding the image quality, the display in a gray raster mode was more uniform than in the first example.

[0051]

Third Example

A liquid crystal panel was produced in which the bottom surfaces of the protuberances 6 in the second example were shaped like a square with four sides of 10 μm, the protuberances 6 had a height of 4.5 μm, and acrylic spacers were not used.

[0052]

As the result of evaluating the driving of the obtained liquid crystal panel in a manner similar to that of the first example, viewing angle characteristics similar to those of the second example were obtained. Regarding the image quality, the display was more uniform than in the second example.

[0053]

Fourth Example

A liquid crystal panel was produced in which the pixel electrodes 1 of the TFT substrate 2' and the protuberances 6 of the color filter substrate 4' were arranged and patterned, as shown in Fig. 4(c). In this case, the width L_1 of slits 7 on the TFT substrate 2' was set at 7 μm. The bottom surfaces of the protuberances 6 had a size such that L_2 = 5 μm, L_3 = 10 μm, L_4 = 5 μm, and L_5 = 10 μm.

[0054]

As the result of evaluating the driving of the obtained liquid crystal panel in a manner similar to that of the

first example, viewing angle characteristics and image quality similar to those of the second example were obtained.

[0055]

Fifth Example

A liquid crystal panel was produced in which the protuberances 6 in the second example were replaced with square holes with four sides of 7 μm which are provided in and ITO electrode.

[0056]

As the result of evaluating the driving of the obtained liquid crystal panel in a manner similar to that of the first example, the image quality was lower than that in the second example, whereas superior viewing angle characteristics were obtained.

[0057]

Sixth Example

A liquid crystal panel was produced in which the R, G, and B color filters 15 in the second example had thicknesses of 1.0 μm, 1.2 μm, and 1.5 μm, respectively, and the particle diameter of acrylic spacers to be dispersed was set at 4 μm. In this case, the optical densities of the color filters were determined so that the same colors as those in the second example could be obtained with the color filters having the above thicknesses.

[0058]

In the obtained liquid crystal panel, a brighter white display was produced, and changes in color balance in the azimuth direction were reduced, compared with the second example.

[0059]

[Advantages]

According to the present invention, in the multi-domain vertical-alignment liquid crystal display device, a wide viewing angle can be achieved without decreasing the effective aperture ratio.

[Brief Description of the Drawings]

[Fig. 1]

Figs. 1(a) and 1(b) are a plan view and a sectional view, respectively, of a liquid crystal display device according to an embodiment of the present invention.

[Fig. 2]

Fig. 2 is an explanatory view showing a method for forming a semicircular protuberance.

[Fig. 3]

Fig. 3 is an explanatory view showing a method for forming a semicircular protuberance.

[Fig. 4]

Fig. 4 is a plan view showing the positional relationship among protuberances, slits, and cuts or holes.

[Fig. 5]

Fig. 5 is a sectional view of a liquid crystal panel.

[Reference Numerals]

1 ... pixel electrode, 2 ... driving substrate, 2' ... TFT substrate, 3 ... counter electrode, 4 ... counter substrate, 4' ... color filter substrate, 5 ... liquid crystal, 6 ... protuberance, 6', 6" ... photosensitive resin patterned to form protuberance, 7 ... slit, 8 ... cut, 9 ... hole, 11a, 11b ... mask, 100 ... liquid crystal display device.

[Name of Document] ABSTRACT

[Abstract]

[Object] To achieve a wide viewing angle without lowering the effective aperture ratio in a liquid crystal display device of a multi-domain vertical-alignment mode.

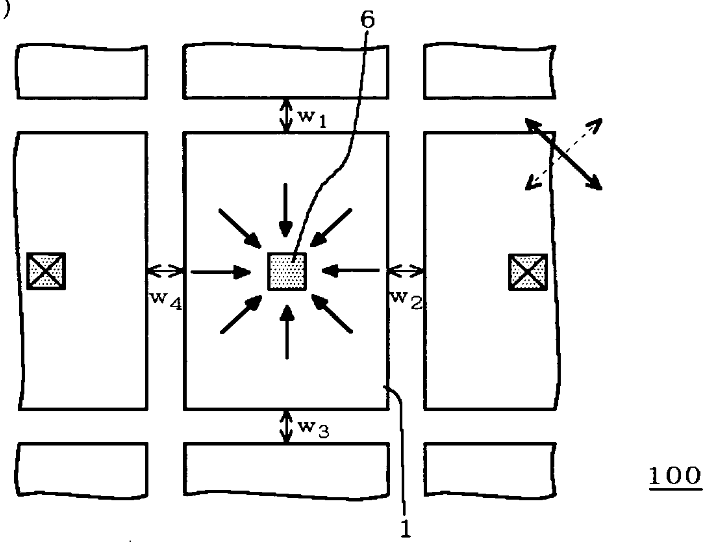
[Solving Means] In a liquid crystal display device 100 of a vertical-alignment mode which includes a driving substrate 2 having pixel electrodes 1, a counter substrate 4 opposing the driving substrate 2 and having a counter electrode 3, and a liquid crystal 5 sandwiched between the substrates, and in which molecules of the liquid crystal are aligned nearly perpendicularly to the substrates 2 and 4 when no electric field is produced, and are aligned nearly horizontally by the application of a predetermined voltage, the counter substrate 4 has a protuberance 6 or an alignment disturbing surface as an alignment center portion that orients the molecules of the liquid crystal in all directions centered on a certain point when a voltage is applied. The area of the alignment center portion on the counter substrate 4 is set to be less than or equal to 5% of the area of one pixel.

[Selected Figure] Fig. 1

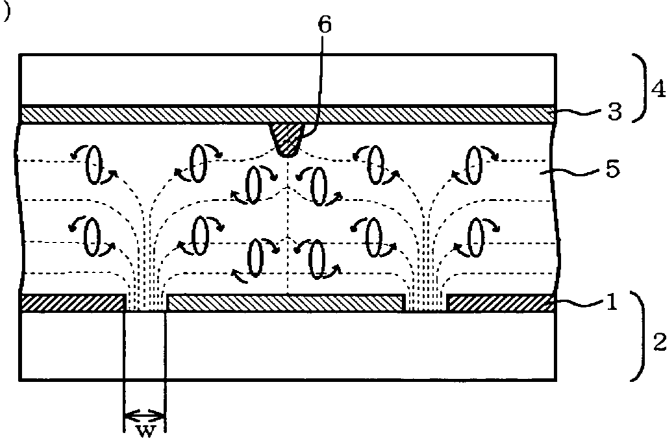
【書類名】　図面　[Name of Document] DRAWINGS

【図１】[Fig. 1]

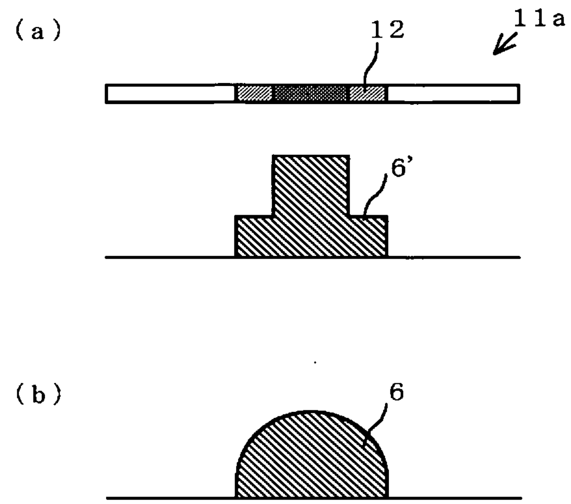
（ａ）



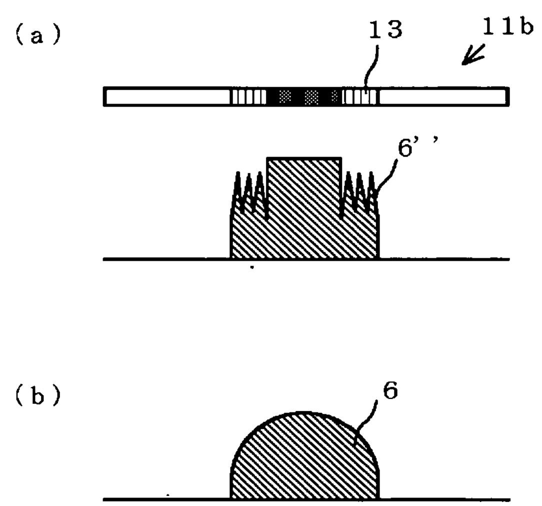
（ｂ）



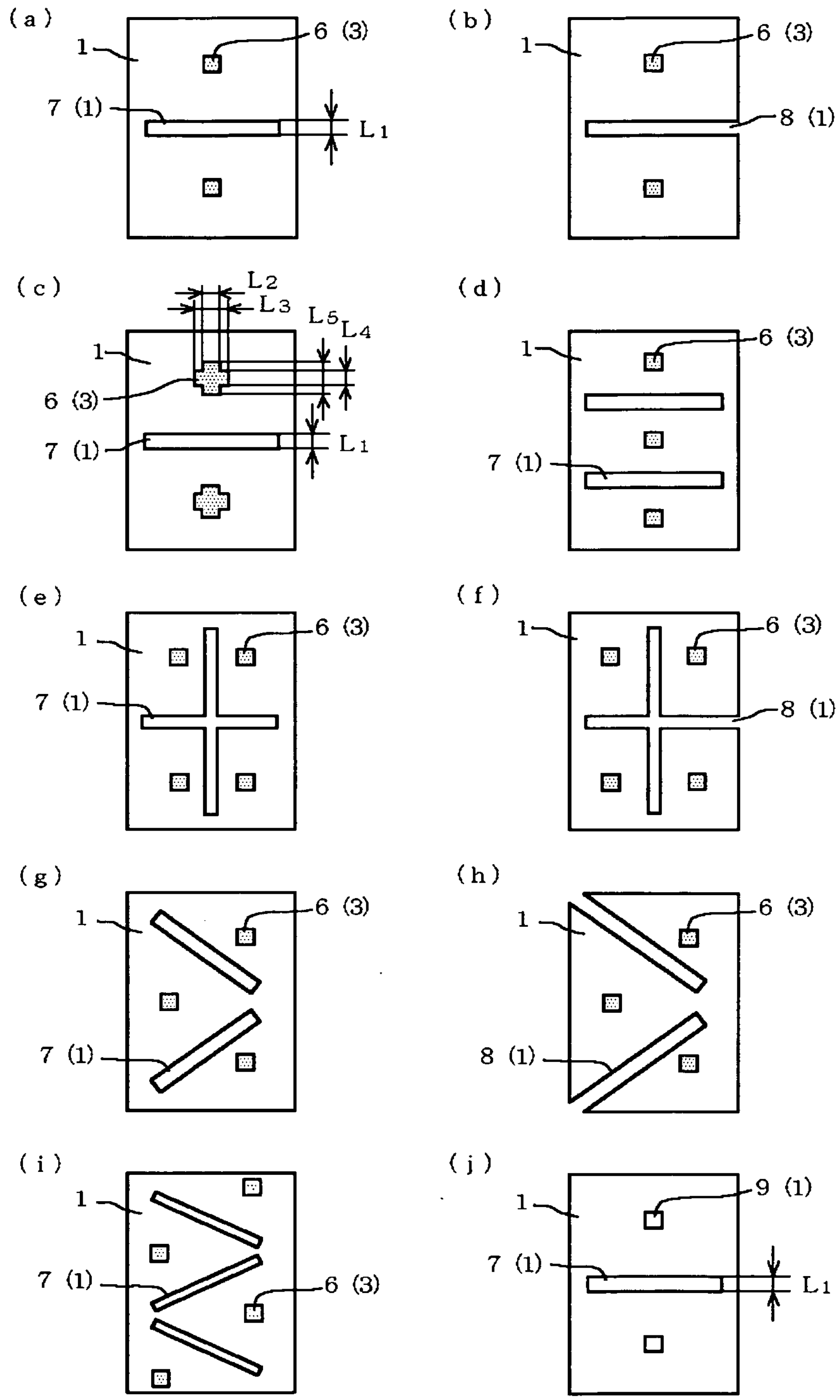
【図２】[Fig. 2]



【図３】[Fig. 3]



【図４】[Fig. 4]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7 (1)
L1
(b)
1
6 (3)
8 (1)
(c)
L2
L3
L5
L4
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L1
(d)
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(e)
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(g)
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(h)
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(j)
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9 (1)
7 (1)
L1

【図５】[Fig. 5]